Center for Chips with Heterogeneously Integrated Photonics (CHIPS)

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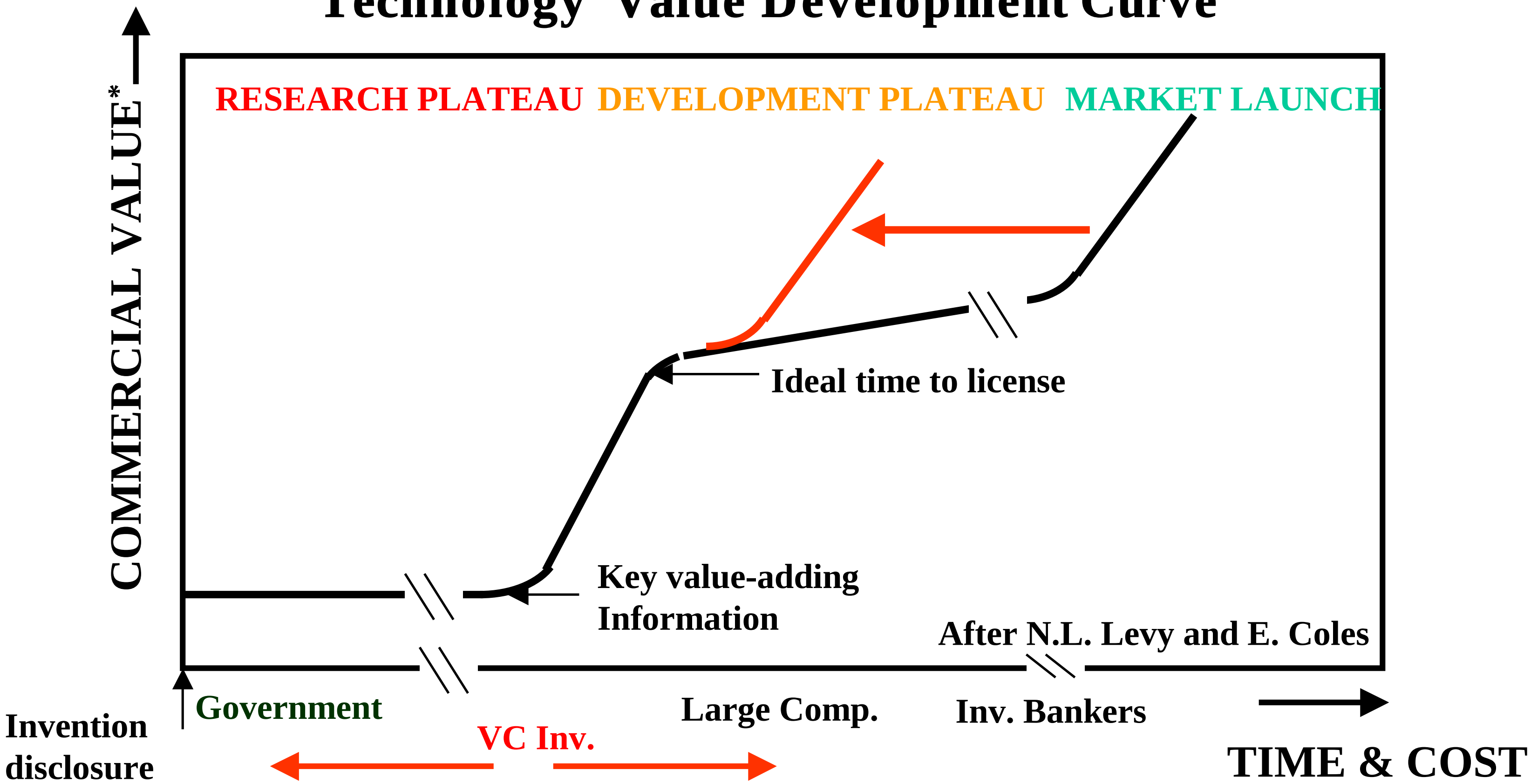
DARPA Opto Centers Kickoff

CHIPS Kickoff Presentations

Speaker	**Topic**	**(min)**
Esener	CHIPS Overview	20
Bhatia	Biophotonics	15
Jalali	SOI Nanophotonics and bio detection	10
Dapkus	Nanophotonics	15
Scherer	Micro-nanofabrication	15
Bowers	Amplification & tunability	15
Campbell	Light Detection	10

Missions of Opto Centers in the New Economy

Technology Value Development Curve



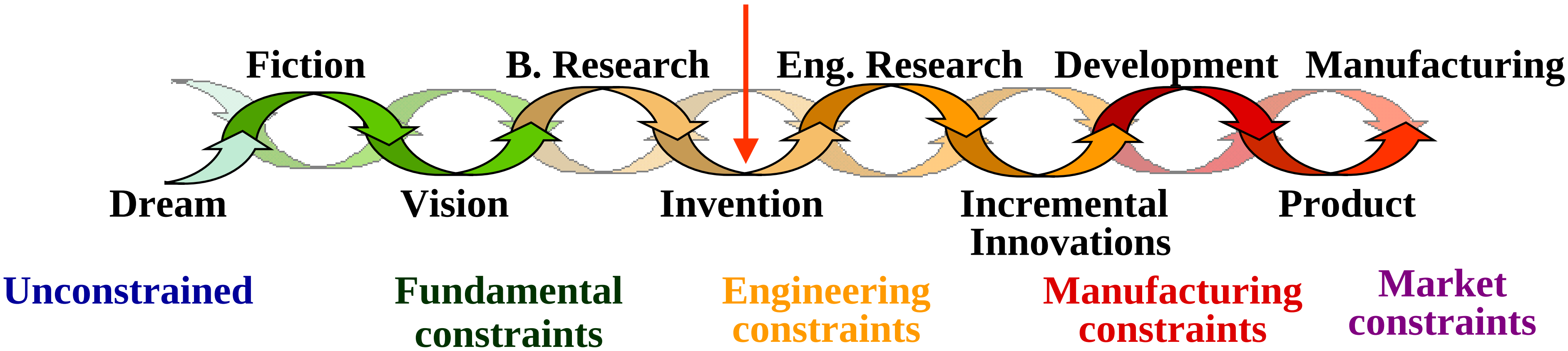
Where should the opto-centers be positioned?

Where should DARPA be ?

Where are the VC Investors going to be?

What happens before the invention disclosures?

Positioning the New Opto-Centers



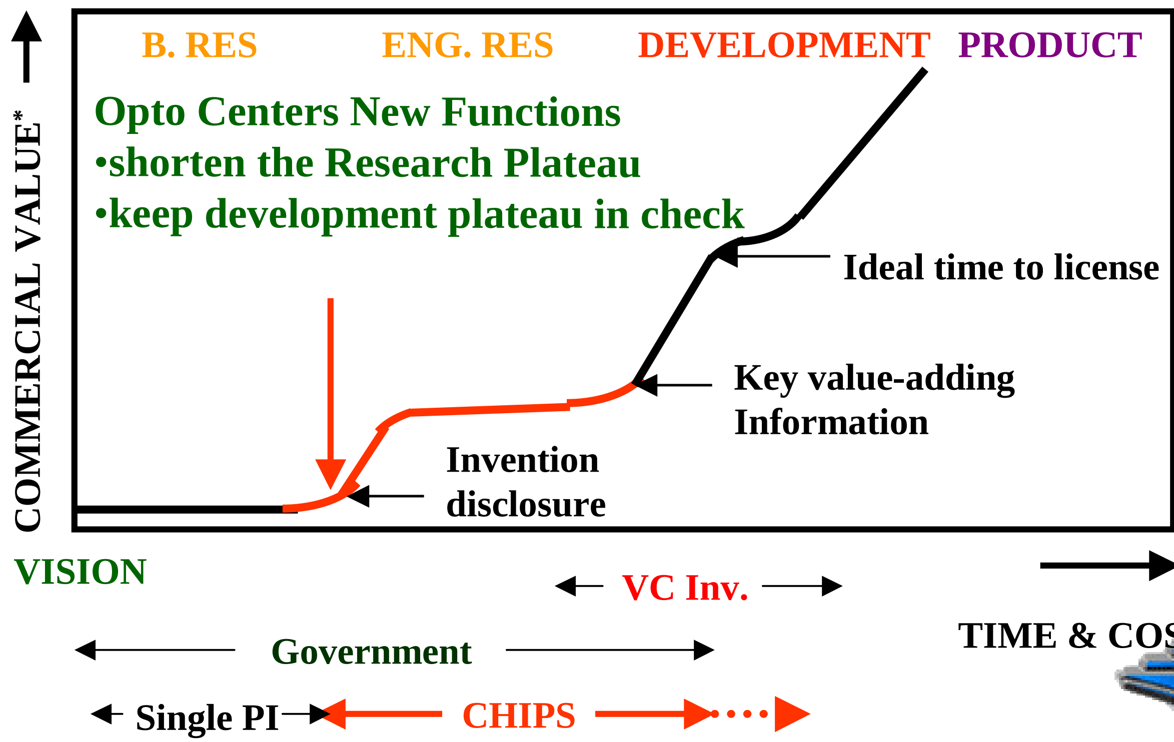
CHIPS OBJECTIVES

Promote Inventions

Facilitate Innovations

Enable links between

- •Basic science research
- •Engineering research
- •Corporate R&D
- •Financing



Center for Chips with Heterogeneously Integrated Photonics (CHIPS)

PI: Sadik Esener; MDA 972-00-1-0019 start: 7-1-2000

Mission:

→ To innovate photonic components beyond classical limits by
- miniaturization,
- multidisciplinary research,
- investigation of new applications and close collaboration with industrial partners

→ To prepare and train future OE workforce for the rapidly growing Photonics Industry

Core Areas:

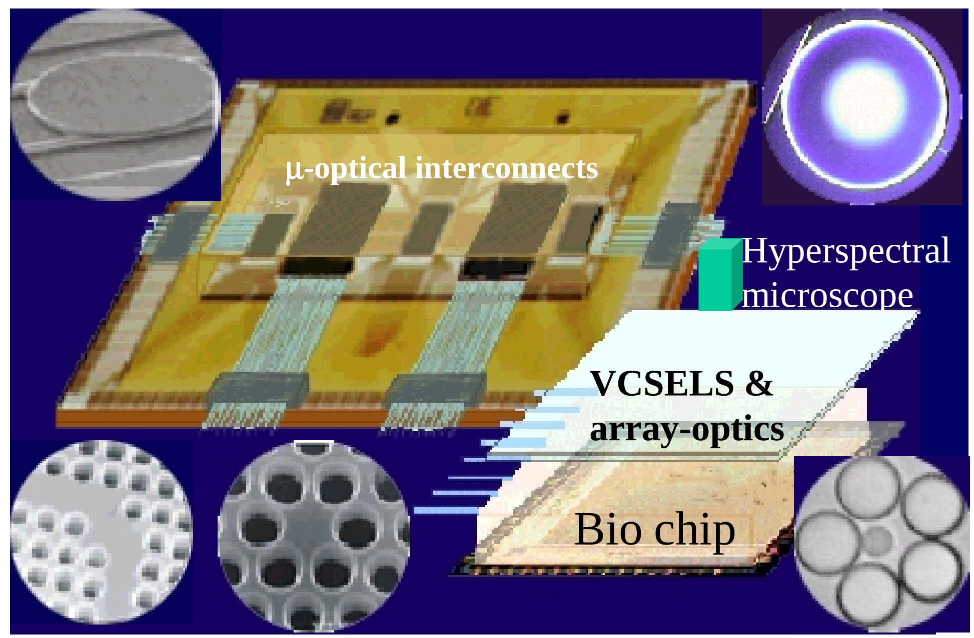
Develop core photonic technologies including
- **Nano, Meso and Near field optics**
- **PBG, and QD lasers**
- **Tunable lasers, detectors, and SOA arrays**
- **Optical μ–beams & volumetric μ-optics**
- **NOEMS**

for enhancing integration at the device, interconnect, and chip levels for **biochip and photonic switching** applications

Core Technology Development Thrust

Biophotonic Chip Thrust

Photonic Switching



CHIPS WORK AREAS

DARPA SUPPORT

INDUSTRY SUPPORT

Core Technology Development Thrust

Physics and modeling of nanophotonics
Materials / Microfabrication / HI
Light sources and detectors
Interconnect Components

Biophotonic Chip Thrust

Microbeam controlled fluidic switch and Pick and Place
Nanophotonics based bio chemical sensors
MEMS microspectrometer arrays
Spectroscopic, confocal and near field two-photon μ-scopes
System Integration

Photonic Switching

PBG Switches
μ-resonator filters, switches and λ-converters
Polymeric integration for ultra flat optical packages
System integration on InP

CHIPS ORGANIZATION

Advisory Board

- Agilent
- Agility
- Boeing
- Corning
- CREE
- E2O
- Gore
- Honeywell
- HRL
- Hughes spectrolab
- Irvine Sensors
- Motorola
- Nanogen
- New Focus
- OMM
- Picolight
- Raytheon
- SDL
- Sun μ-systems
- Telcordia
- TRW
- Vitesse
- Xerox

Administrative Board

Esener, Director
Wu, Assoc. Director

Technology Exchange Board

<u>Coldren</u>	H-Brenner HTC
Dapkus	Lytel (SUN)
Wu	Ishak (Agilent)

Program Management Council

7 Primary Investigators

Caltech
<u>Vahala/Psaltis</u>

Quake
Psaltis
Scherer

UCLA
<u>Wu</u>

Jalali
Ho
Yablonovitch

UCI
<u>Rentzepis*</u>

UCSD
<u>Esener</u>

Bhatia
Fainman
Lo

UT Austin
<u>Campbell</u>
Huffaker*

UCSB
<u>Coldren</u>

Bowers
Hu
DenBaars

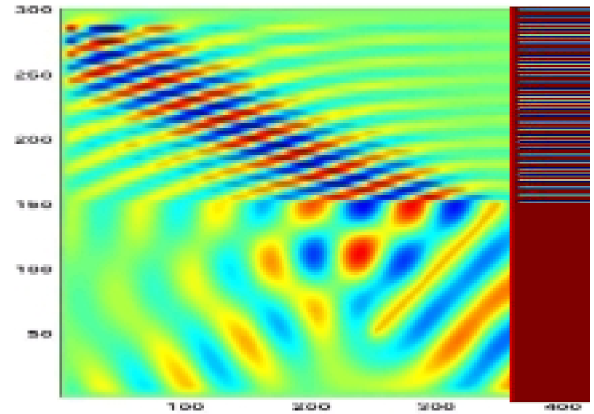
USC
<u>Dapkus</u>

O'Brien
Levy
Steier*/Kim*

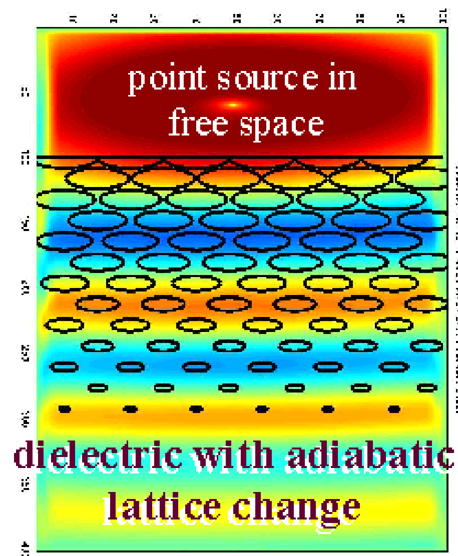
Nanophotonic Device Modeling

A. F. J. Levi, J. D. O'Brien and S. Fainman, USC/UCSD

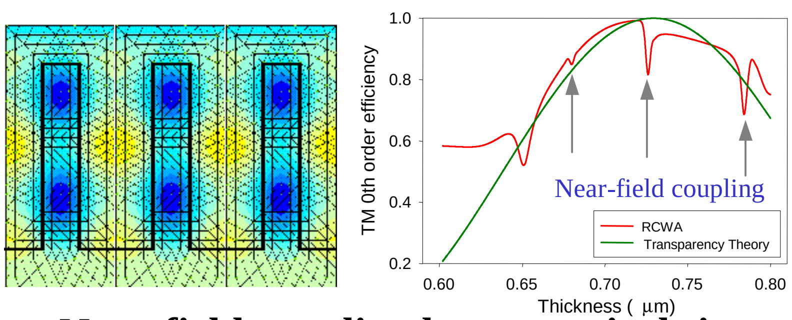
- **Develop efficient modeling tools for adiabatic non periodic photonic crystal device structures**
- **Design components with increased functionality that overcome existing barriers to photonic crystal implementation**
  - **Optical coupling structures**
  - **Low loss wavelength selective guided wave structures**
- **Demonstrate proof of concept devices**



Dispersive propagation allows manipulation of many λ's independently



Reducing the insertion loss into a dispersive optical element



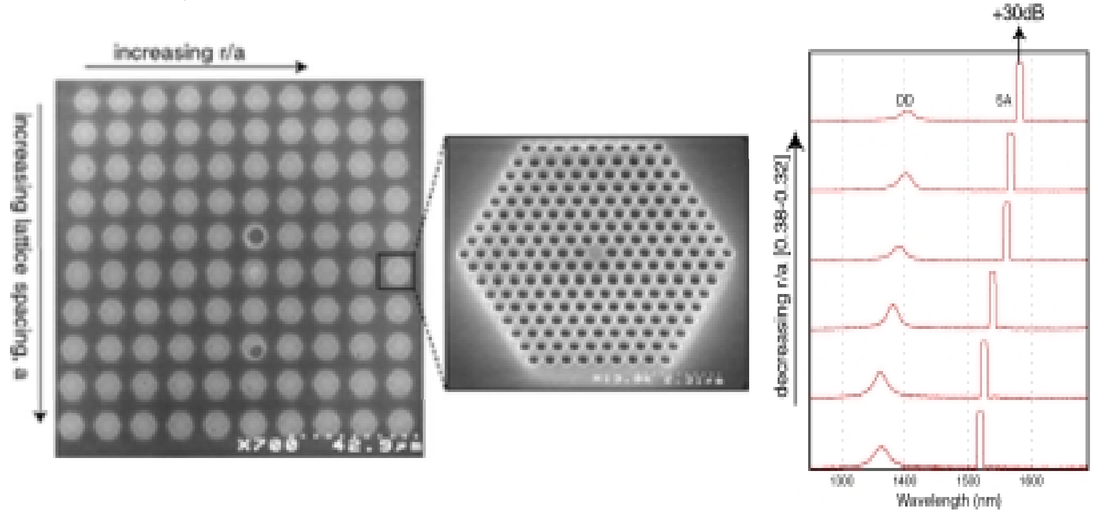
Near-field coupling between pixels in Form-birefringent CGH

Quantum Dots in Photonic Crystals

Axel Scherer, Caltech

Objectives

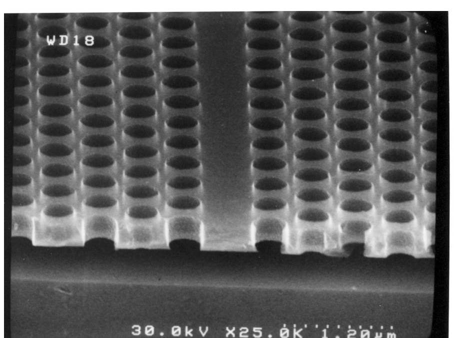
- Design and construct high Q photonic bandgap (PBG) nanocavities
- Investigate tunability of nanocavities due to nonlinear effects
- Couple nanocavities with waveguides for optical logic systems



Lithographically tuned multiple wavelength photonic crystal laser array

Impact

- Photonic crystal cavities have been used to construct ultra-small nanocavity lasers
- By combining the small volumes and high cavity Qs with narrow linewidth light sources, we can make very efficient optical switches



Cross-section through a photonic crystal waveguide which can be used to couple optical cavities together

Accomplishments

- We have fabricated and lithographically tuned photonic crystal nanocavity lasers
- We observe narrow resonance peaks in quantum dot photonic crystal nanocavities
- We have designed and fabricated efficient photonic crystal waveguides

SOI Nanophotonics

M. Wu, Yablonovitch, Jalali, UCLA

OBJECTIVE:

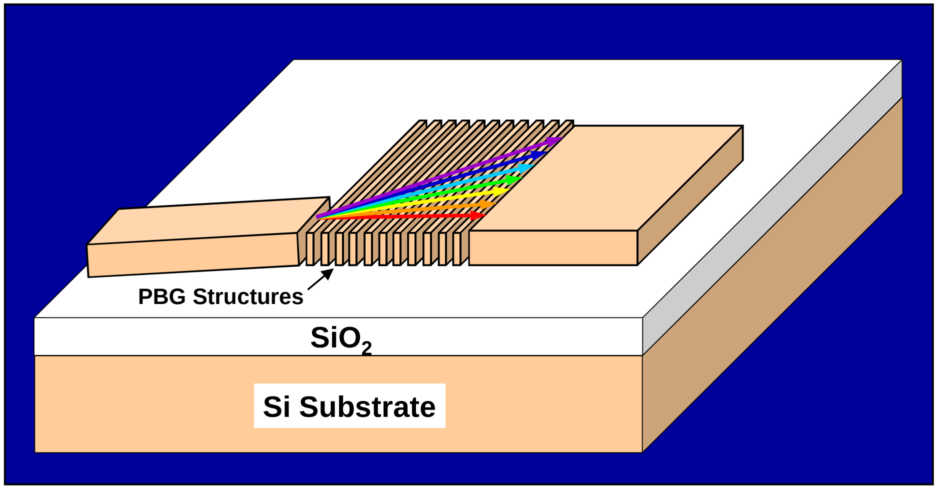
- Develop ultra-compact, low-cost microspectrometers for
  - bio/chemical sensing
  - spectroscopy
  - optical communications
  - RF signal processing

APPROACH:

- PBG + NEMS + SOI
  - PBG: Photonic Band Gap
  - NEMS: Nanoscale MEMS
  - SOI: Silicon on Insulator
- Nanofabrication using DRIE (deep reactive ion etching)
- SiGe and SiGeC bandgap engineering and photodetectors
- Compatible with CMOS

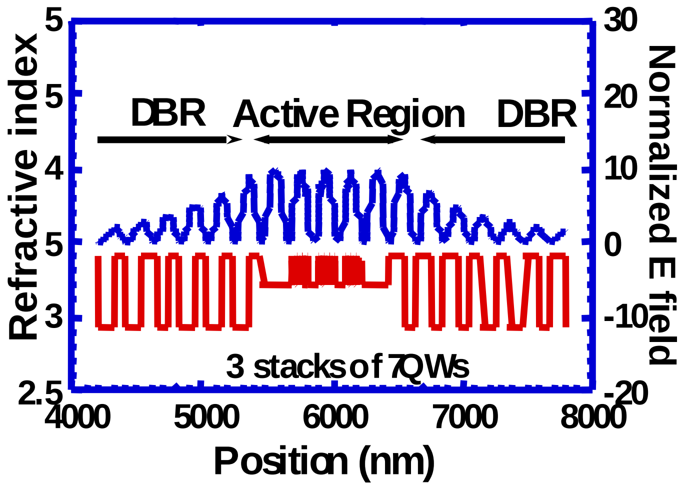
MILESTONES AND SCHEDULE:

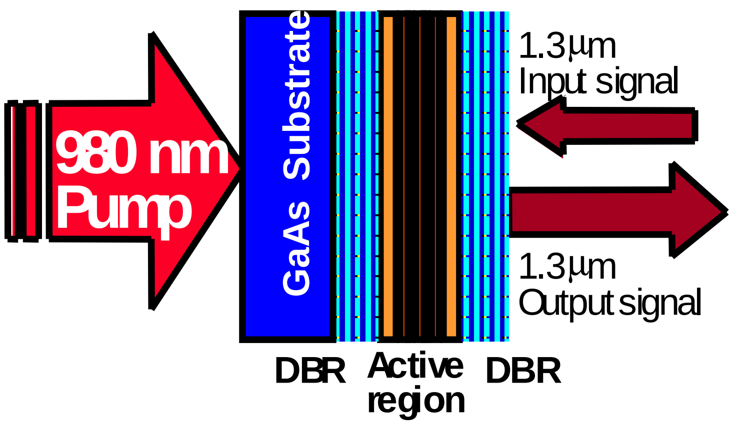
- Develop nanofabrication techniques on SOI (12 mo.)
- Demonstrate 1-D superprism (18 mo.)
- Demonstrate NEMS devices (24 mo.)
- Bandgap engineering (SiGeC) and detector integration (36 mo.)



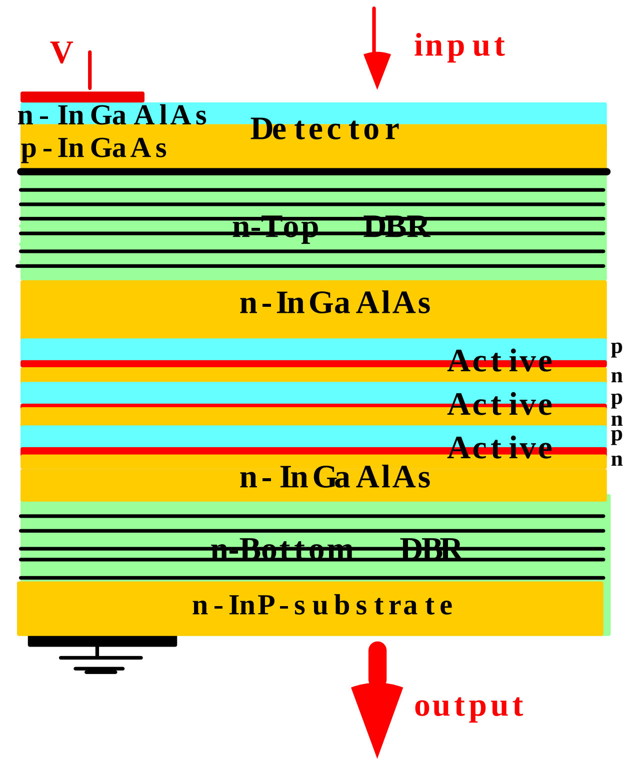
Advanced VCL devices

L. Coldren, J. Bowers (UCSB), S. Esener (UCSD)





Surface-normal optical amplifier switch



Surface-normal transparent wavelength converter.

Optically-pumped VCSEL-amps and MAR-VCSELs allow larger numbers of quantum wells and higher gain enabling

- Vertical high-contrast switches and EO-tunable VCSELs.
- WDM arrays of VCSELs by bonding or epi-regrowth.
- Novel λ-converters and pre-amplified receivers/integrated detectors

Ultra Low Noise Avalanche Photodiodes

J. C. Campbell UT-Austin

Objective

Develop avalanche photodiodes that achieve ultra low multiplication noise and high bandwidths.

Approach

- **Impact-ionization-engineered multiplication regions**
- **Unconventional materials**
- **Heterogeneous integration of device functions**

Research Issues

Impact ionization engineered gain regions:

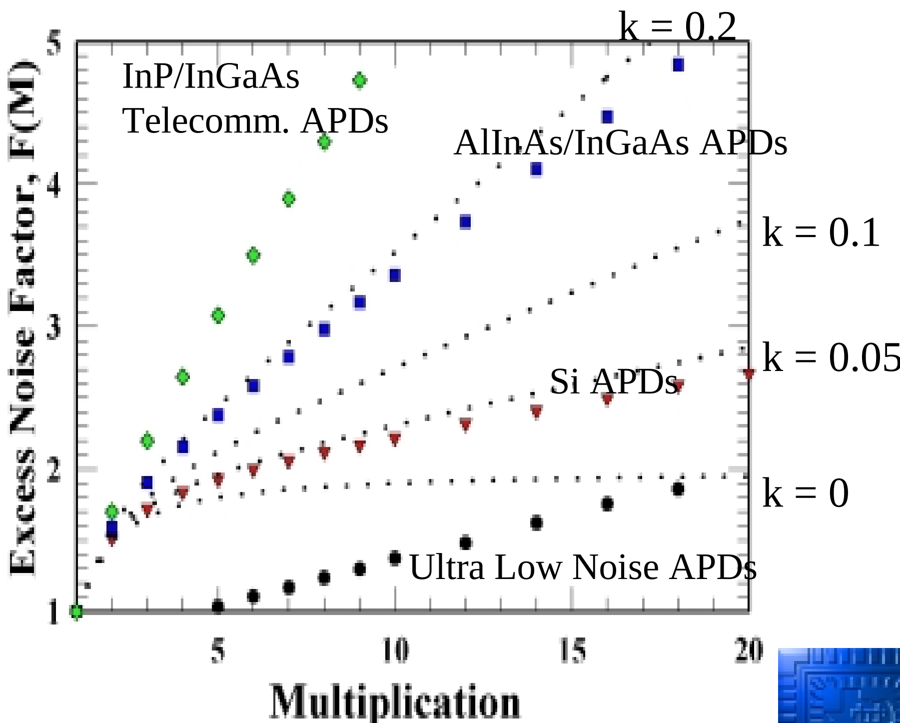
- **Determination of noise reduction mechanisms**
- **Extension to "long-wavelength materials"**
- **Development of theoretical models**

New materials:

- **Characterization of noise and non-local effects**
- **AlGaAs/GaAsN for low noise and long wavelength**

Heterogeneous integration:

- **Fusion of low noise AlGaAs-based multiplication regions to long-wavelength absorption layers**



Electrophoretically controlled lenslet arrays

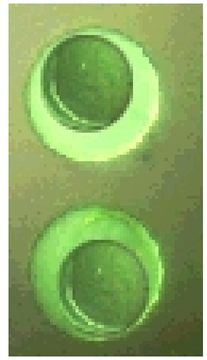
S. Esener (UCSD)

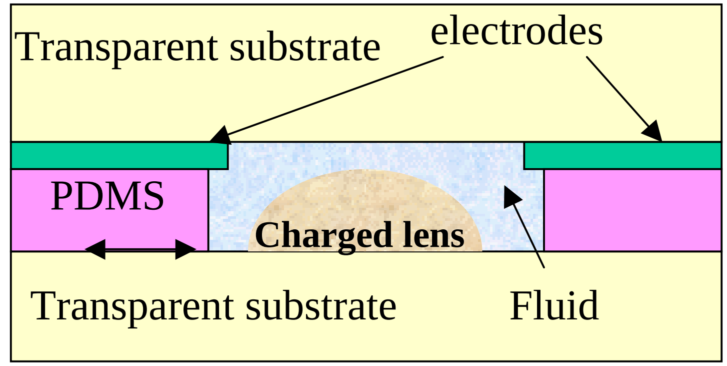
Objective:

CMOS compatible dynamically reconfigurable lenslet array

Approach:

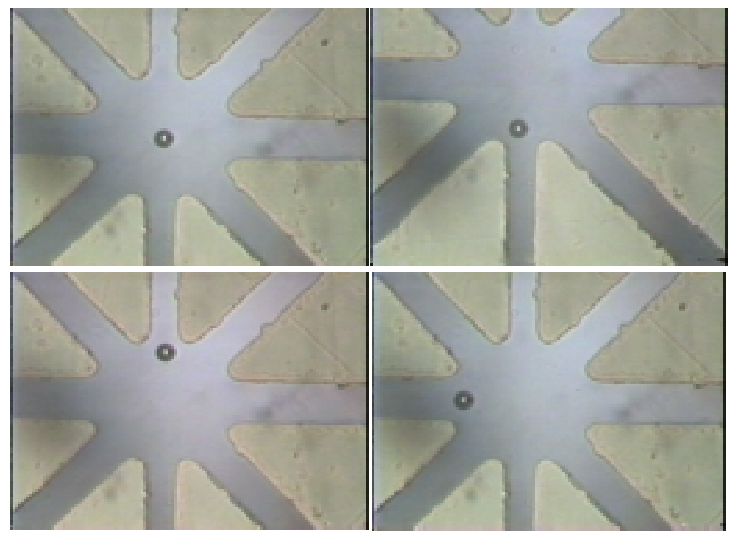
Use electrophoretic forces to position charged lenslets with ultra low drive voltage and current





Feasibility Demonstrations

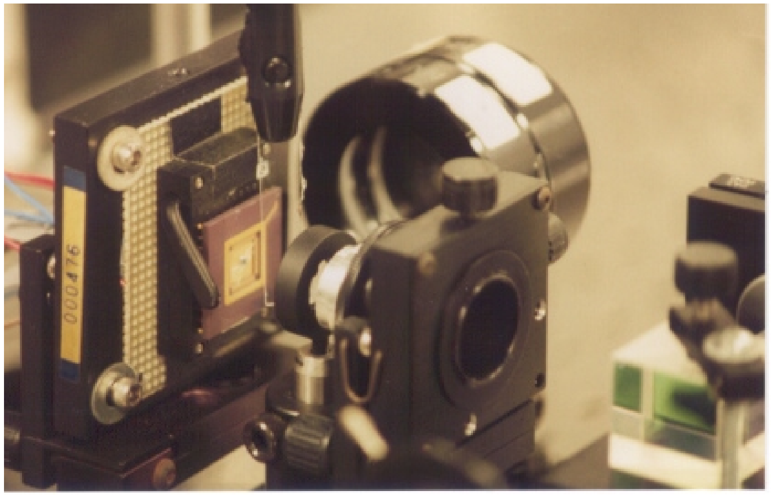
Sphere Diameter = 20µm
Electrode Separation = 100µm
Voltage Applied = ± 3 V
DC Current = 1.1 µA
Average Speed ~ 5µm/s



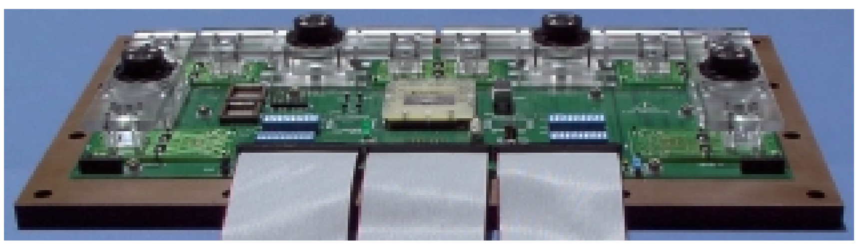
Scaling of Optical Systems

using VCSEL Driven Optical μ-beams

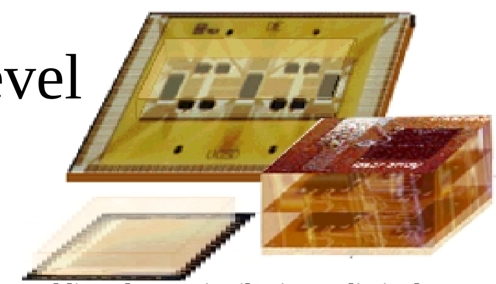
Optical Interconnects



Board level use of optical μ-beams

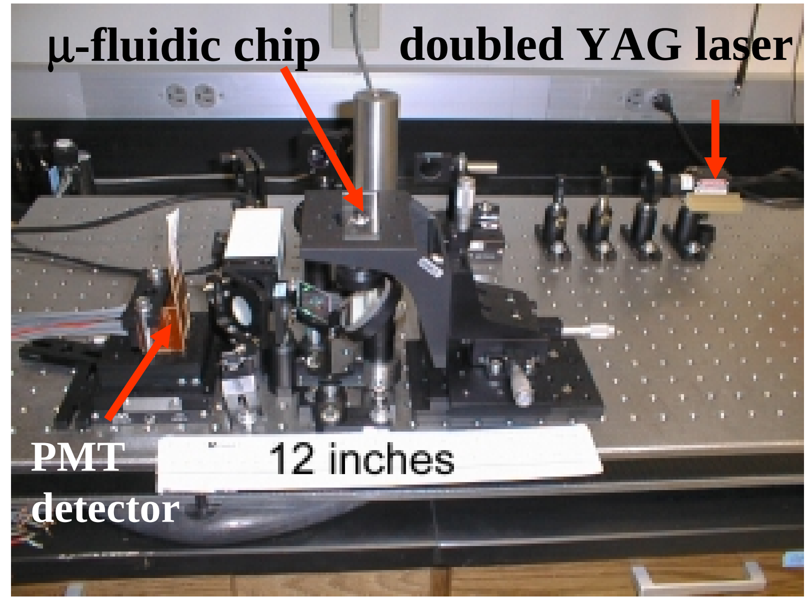


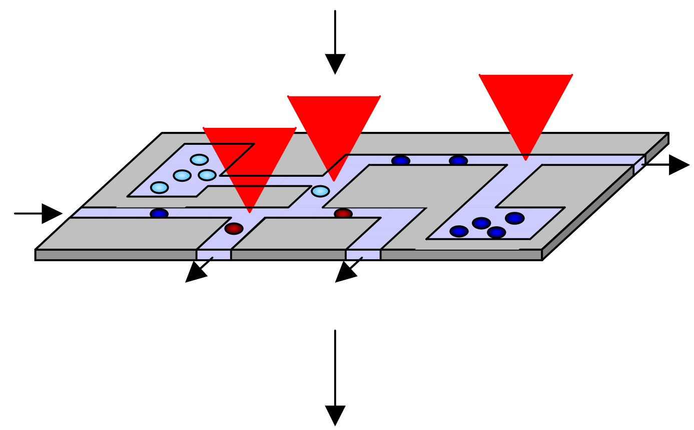
Chip level



Approved for Public Release, Distribution Unlimited

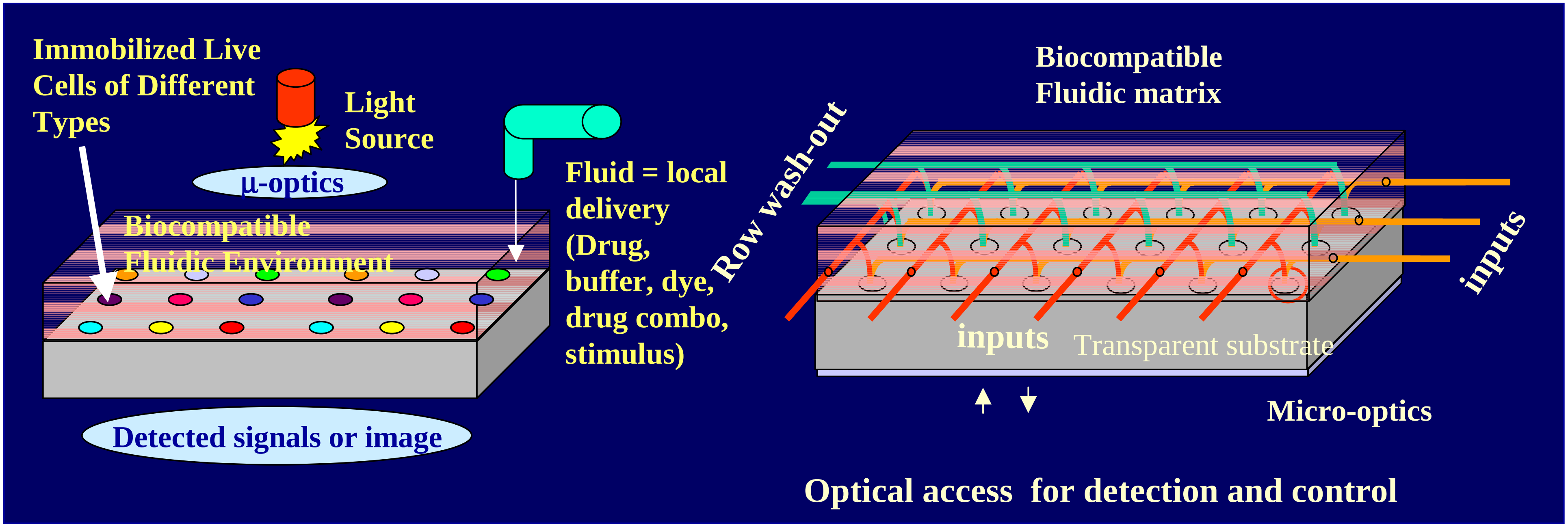
Biochips





Chip level HI

Advanced bio-photonic chip



- Arbitrary local fluidic environment (pH 7.4)
- **Spatial localization of biological substance**
- **Sensing of small signals**
- **Micro fluidic delivery (nL)**
- **Real-time Interactive (video rate)**
- Disposable/Inexpensive
- Biocompatible

Optical pick and place
Optically controlled fluidic switch
Optical sensing
Optical sorting
Optical cell photolysis
Optical I/O access

UCSD

VCSEL Optical Tweezer Array enabled Optical Pick and Place

Esener-Bhatia

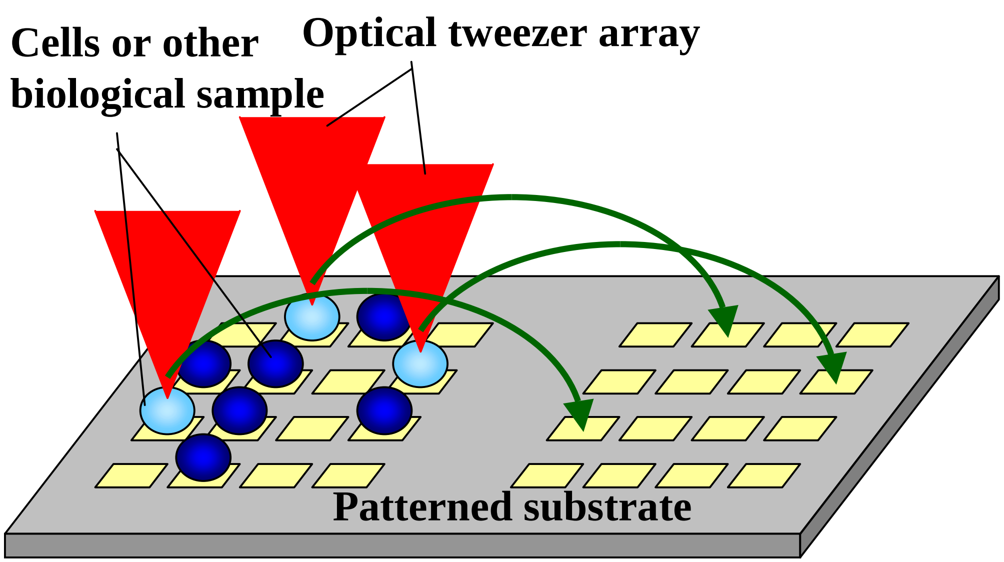
Objective

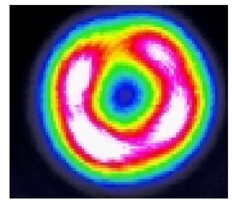
Pick and Place and switching of organic and inorganic objects by applied electric field and by VCSEL driven optical μ-beams

- **Massively parallel positioning**
- **Manipulation of individual object**

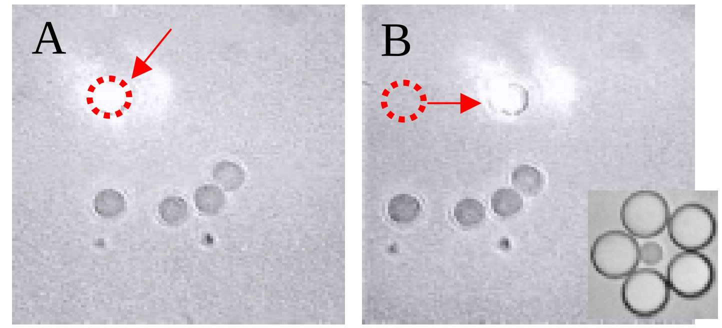
Approach

Electrophoretically pre-positioned objects carried by VCSEL driven micro beams to desired location

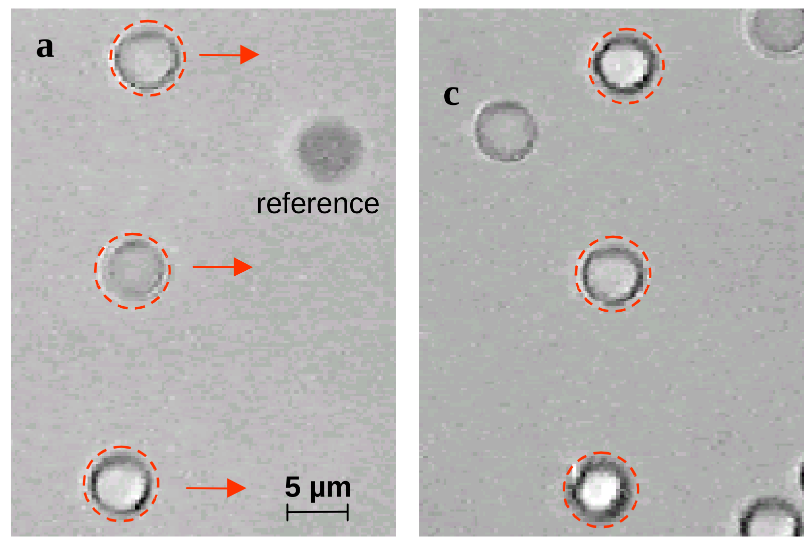




Laguerre-Gaussian mode



A 5 μm polystyrene bead has been picked and placed by VCSEL driven micro beam to a different location



Particle Switching in Microfluidics

Objective

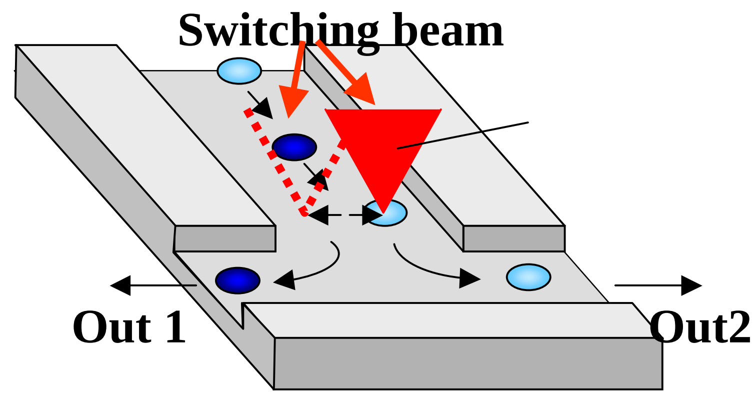
Parallel Switching of organic and inorganic objects by VCSEL driven optical μ-beams

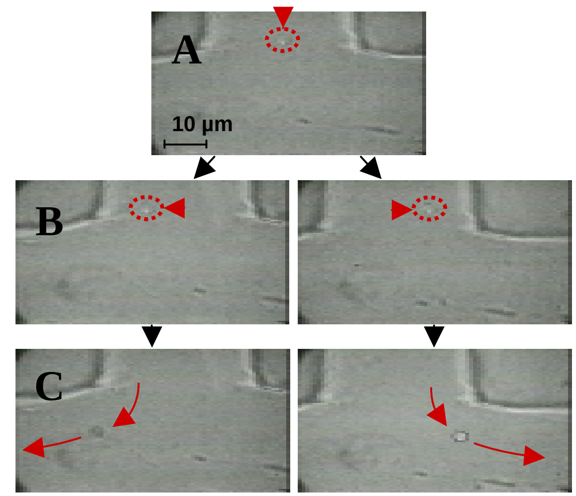
Approach

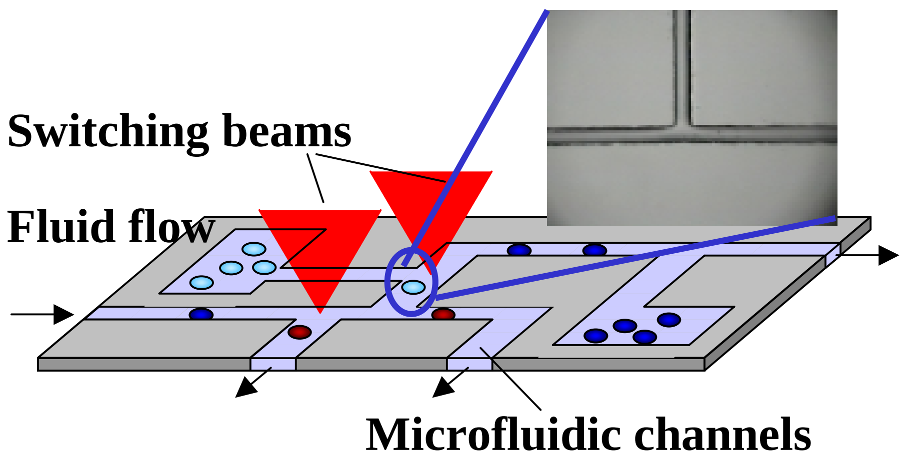
Particles directed by optical micro beams focused at junction. Investigate

1.) ***Attractive gradient force***

2.) ***Repulsive scattering force***

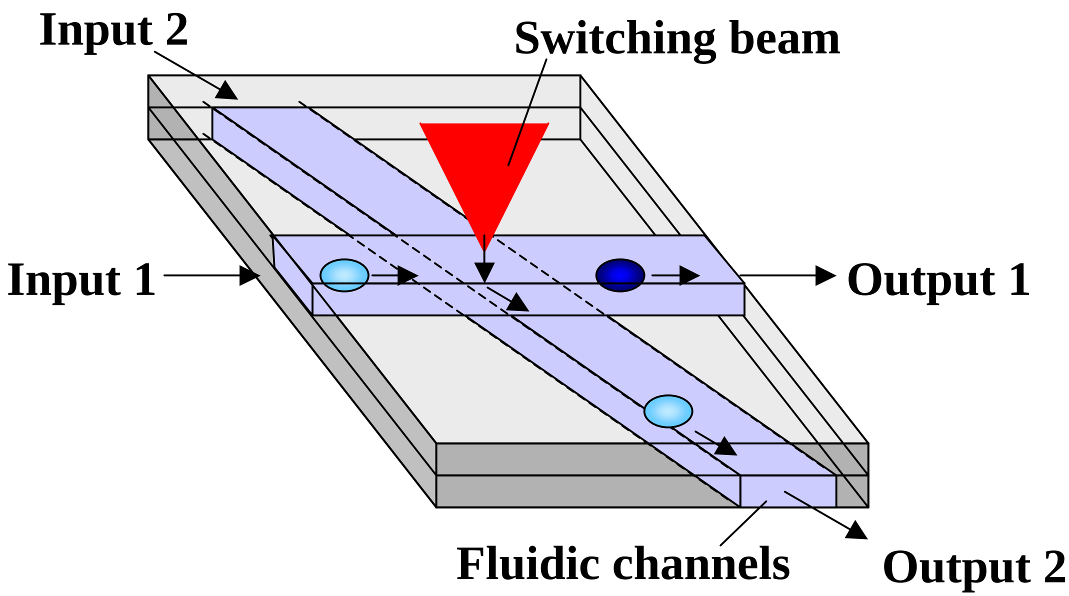


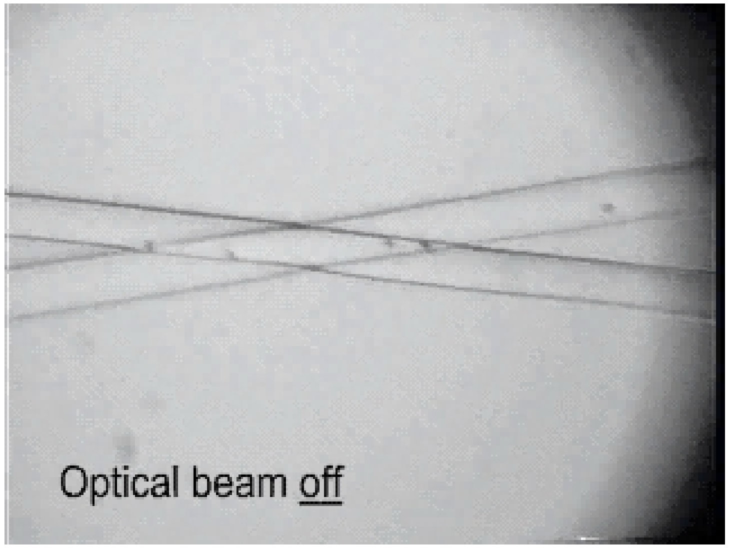




- **Continuous fluid flow induced by electro-osmosis.** (linear flow rate: 30 μm/sec @ 16 volts) Used 20mw

Scattering Force Switch

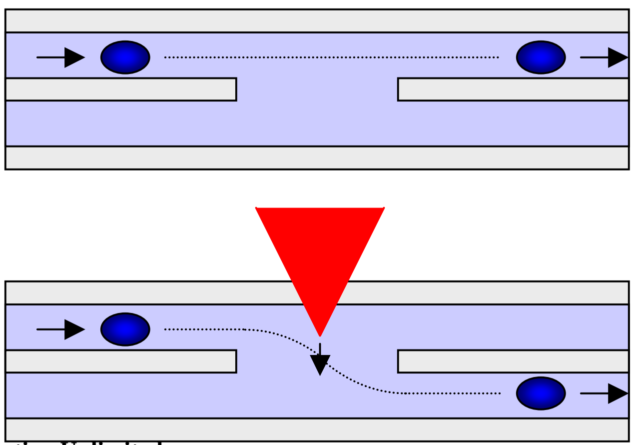




View from the side:

Optical beam **off**:

Optical beam **on**:



- Low N.A. optics, therefore low gradient force.
- Dominant scattering force acts as "elevator" between upper and lower levels.

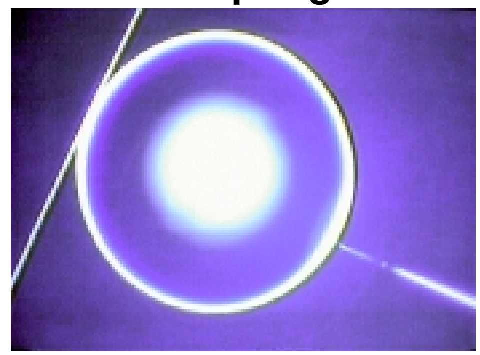
Microsphere Biochemical Sensor

Kerry Vahala, Steve Quake, Sangeeta Bhatia, Sadik Esener

Objective: Develop a novel all-fiber-optic biochemical sensor based on ultra-high-Q microsphere resonators that are functionalized for detection of specific agents.

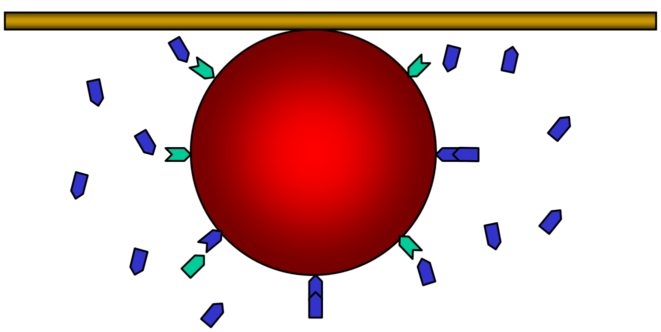
Participants: Kerry Vahala, Steve Quake, Sangeeta Bhatia, Sadik Esener

Critical coupling sensor



Cai, Painter, Vahala, Phys. Rev. Lett. July 3, 2000

Functionalized micro-resonator



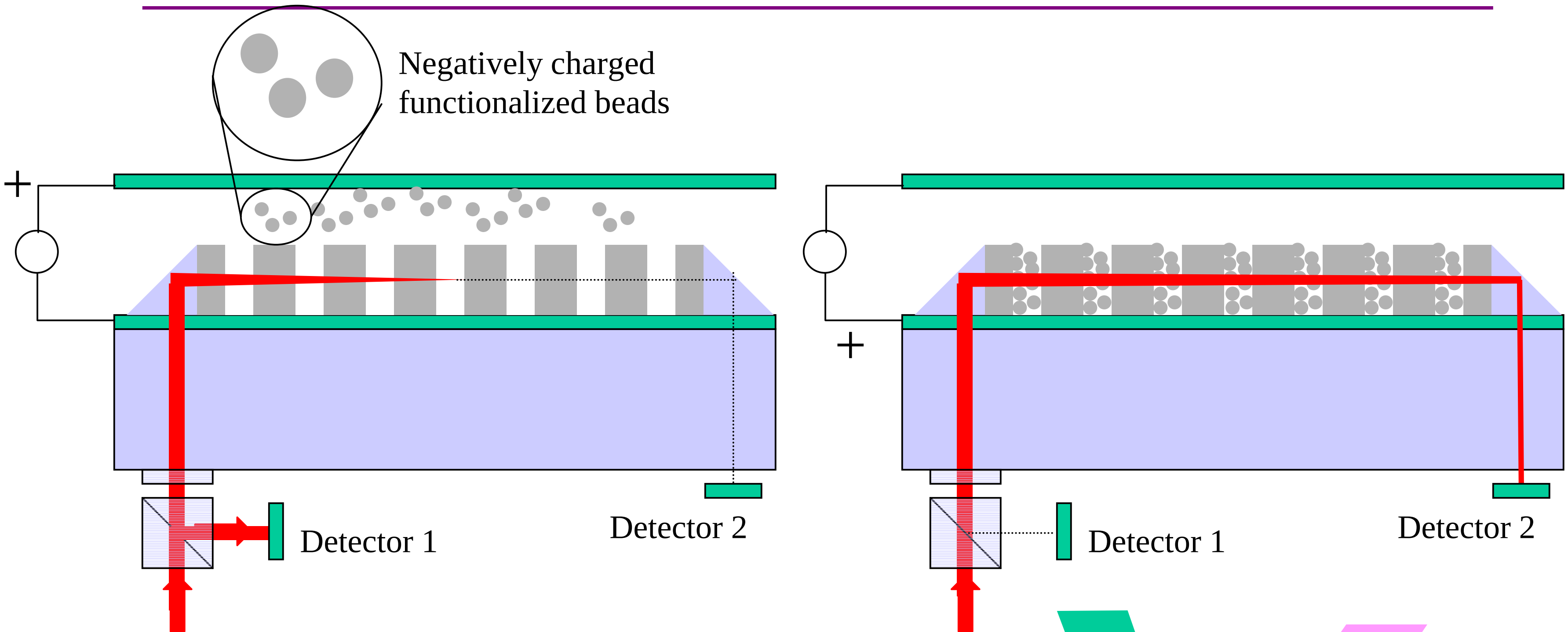
Measurements:

Sensor will be tested on a number of known agents to verify sensitivity.

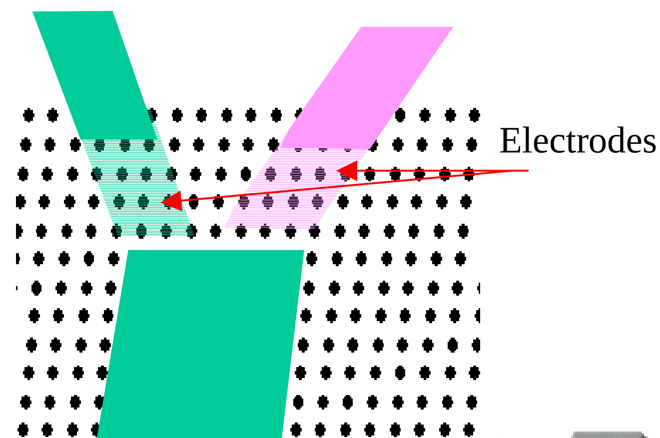
Manipulation of spheres using pick and place techniques will be studied

PBG/grating electrophoretic bio-fluidic sensor /photonic switch

Esener/Bhatia/Scherer/Quake



Variety of functions ranging from
genomic chips (Fluorescence not needed)
enzyme detection
photonic switch depending on optical efficiency



Variety of different geometries possible
Including volumetric and parallel arrays
and guided wave

Bio-Chip Optical Imaging

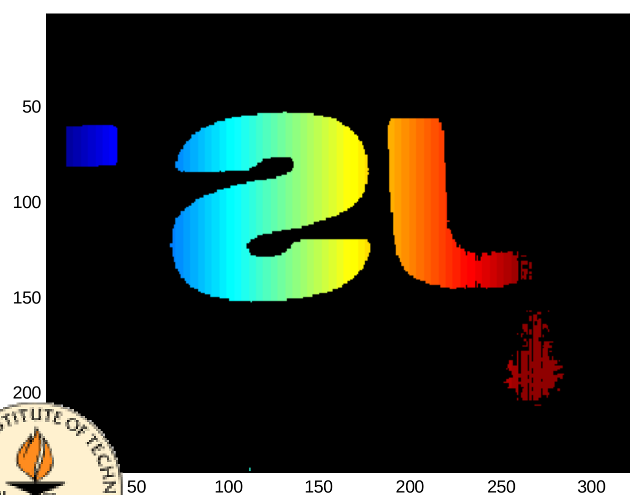
Psaltis, Fainman, Lo, Esener

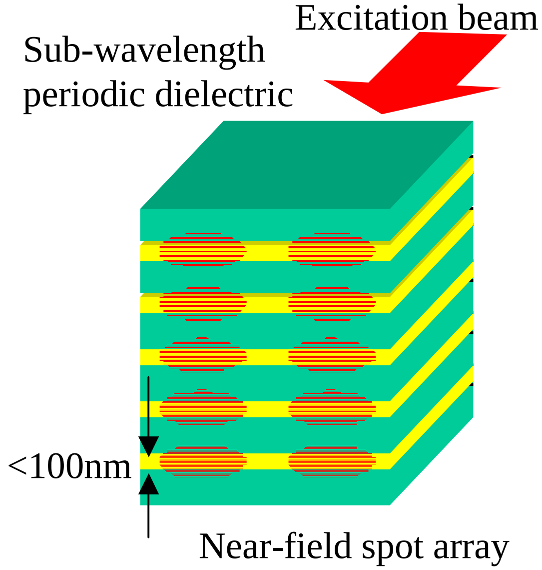
To explore advantages of

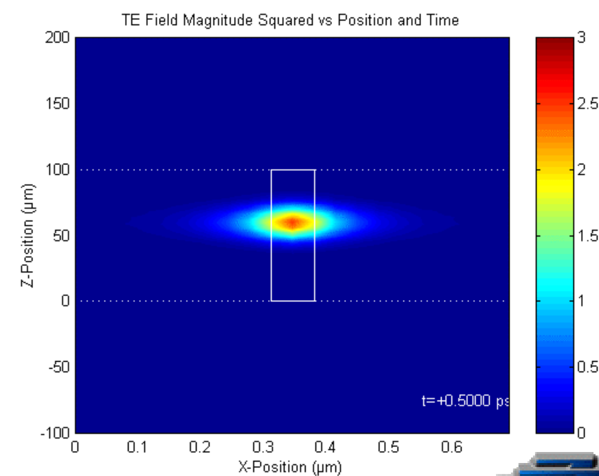
- 4-D λ-Confocal microscopy
  - Volume localization
- Two-photon microscopy
  - IR has little effect on surrounding bio tissue
  - 2-photon focus point defines a reduced "confocal" volume.
- Near-Field Microscopy
  - Resolution
- Parallelism
  - Throughput

Enabling technologies

- Holography-Micro-optics
- Nanophotonics
- MEMS







Heterogeneous Integration Research

Objectives

- *Integrated processes for functional nanophotonic subsystems*
- *Seamless integration of diverse device technologies.*

Tools

✓*Heterogeneous Integration*

✓*Electron Beam Lithography*

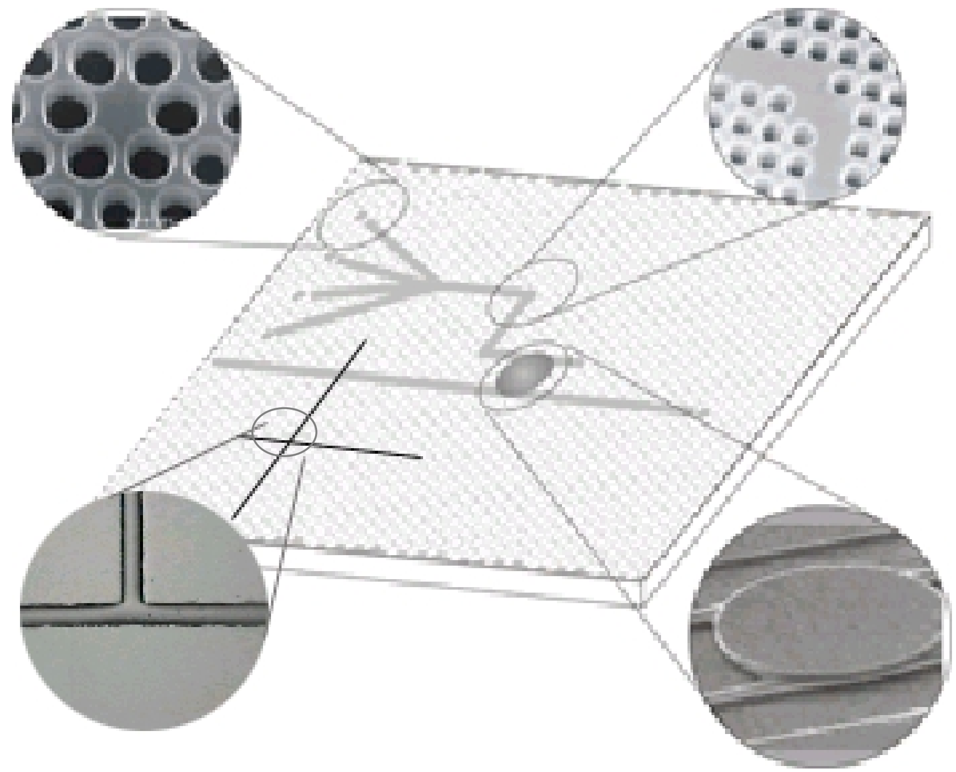
✓*Highly Asymmetric Dry Etching*

✓*Selective Area Epitaxy*

✓*QW and QD Active Regions*

Photonic Crystal Defect Nanolasers

Photonic Crystal Waveguide Components



Biophotonic Components

Active and Passive μ resonator Components

DARPA FUNDED CHIPS TASKS

Photonics Technology Development Thrust

Task 1.1 Physics and modeling

Photonic Crystal, μ-Resonator and near field optics modeling

Task 1.2 Materials / Microfabrication / Heterogeneous Integration

Selective area oxidation and growth, wafer fusion

SOI,Etching, and self assembly technologies for nanophotonics

Task 1.3 Light sources and detectors

PC-QD based Laser formation and study

1.55μm InP based and VCSEL structure based devices

Avalanche and multi spectral photodetector arrays

Task 1.4 Interconnect Elements

PBG waveguides

Superprism

Polymer optical interconnect components

λ-converters

Biophotonic chip thrust

Task 2.1 Biophotonic components for on-chip integration

Microbeam control, optically actuated fluidics and pick and place

Photonic Bio-chemical sensors

λ-peak shift detection for enzymatic reaction sensing

Task 2.2 Analytical bio-photonics sub-systems

2D Arrays of micro-spectrometers

On chip near field two-photon array microscope

System for spectroscopic 3-D imaging of fluorescent probes